United States Government Accountability Office

Report to Congressional Requesters

November 2017

INTERNET OF THINGS

FCC Should Track Growth to Ensure Sufficient Spectrum Remains Available

Accessible Version

GAO-18-71

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GAO Highlights

Highlights of GAO-18-71, a report to congressional requesters

Why GAO Did This Study

IoT generally refers to devices (or "things"), such as vehicles and appliances, that use a network to communicate and share data with each other. The increasing popularity of wireless IoT devices that use spectrum has created questions about spectrum needs. GAO was asked to examine issues related to spectrum and IoT. This report discusses, among other things, (1) spectrum challenges related to IoT, (2) how the federal government plans for IoT's spectrum needs, and (3) how selected leading countries prepare for IoT's spectrum needs.

GAO reviewed documents and interviewed officials from FCC and the National Telecommunications and Information Administration as well as 24 officials from a variety of sectors, including government, commercial, and manufacturing. Stakeholders were selected based on a literature review, among other factors. GAO interviewed government and commercial representatives from four leading countries regarding IoT planning and development and reviewed associated documents. These countries were selected based on criteria that included level of economic development among other criteria.

What GAO Recommends

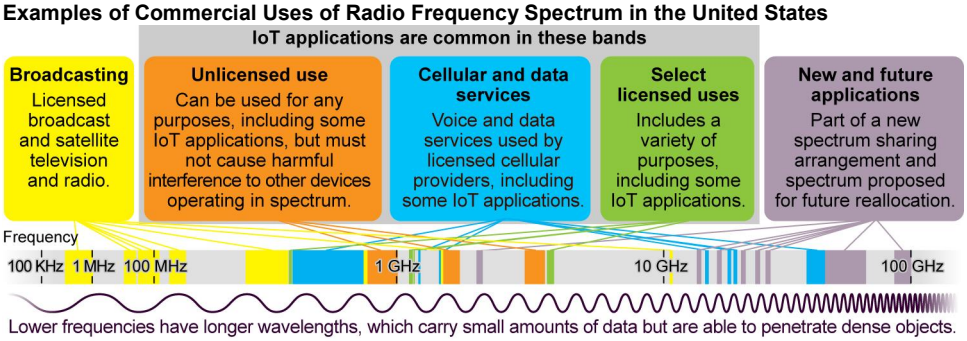
FCC should track the growth in (1) high-bandwidth IoT devices and (2) IoT devices that rely on unlicensed spectrum. FCC did not believe these actions are necessary but noted that it would ask its TAC to periodically review and report on IoT's growth. GAO continues to believe the recommendations are valid.

View GAO-18-71. For more information, contact Mark Goldstein at (202) 512-2834 or goldsteinm@gao.gov.

What GAO Found

The stakeholders GAO spoke with identified two primary spectrum-related challenges for the internet of things (IoT)—the availability of spectrum and managing interference. Although not considered an immediate concern, Federal Communications Commission (FCC) staff and some stakeholders noted that rapid increases in IoT devices that use large amounts of spectrum—called high-bandwidth devices—could quickly overwhelm networks, as happened with smart phones. Stakeholders and FCC staff also indicated that managing interference is becoming more challenging as the number of IoT and other wireless devices grows, particularly in bands that do not require a spectrum license. The figure below illustrates the uses of radio frequency spectrum, including unlicensed use.

Examples of Commercial Uses of Radio Frequency Spectrum in the United States



Source: GAO analysis. | GAO-18-71

FCC plans for IoT's spectrum needs by broadly tracking spectrum demand and making additional spectrum available as needed. Ensuring sufficient spectrum to support commercial demand is one way FCC pursues its strategic goal of promoting economic growth. FCC has made additional spectrum publicly available at least four times since 2015 by repurposing over 11 gigahertz of spectrum. However, FCC does not track the growth of IoT devices in two areas that pose the greatest risk to IoT's growth—high bandwidth and unlicensed-spectrum devices. In 2014, FCC's Technical Advisory Council (TAC) recommended that FCC monitor high-bandwidth IoT devices and make sufficient unlicensed spectrum available. FCC officials said that FCC monitors spectrum use broadly and makes spectrum available as needed. However, since the process of reallocating spectrum is lengthy, FCC may not have adequate time to take actions to avoid a shortage, possibly hindering IoT's growth and associated economic growth.

Spectrum planners in four leading countries—France, Germany, the Netherlands, and South Korea—have taken steps similar to those taken by the United States in preparation for IoT's expansion, including taking a technology-neutral approach that stakeholders believe encourages innovation. Unlike the United States, officials from two leading countries said they are concerned about spectrum congestion from the growth of IoT devices, but only one is actively monitoring congestion. In addition, three leading countries have developed nationwide low power wide-area networks that use unlicensed spectrum with potential benefits including low costs and low barriers to entry.

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Abbreviations

5G	fifth-generation mobile wireless technology
FCC	Federal Communications Commission
GHz	gigahertz
IoT	Internet of Things
ITU	International Telecommunication Union
kHz	kilohertz
LPWAN	low power wide-area network
MHz	megahertz
OECD	Organisation for Economic Cooperation and Development
NTIA	National Telecommunications and Information Administration
RFID	radio-frequency identification
SAS	Spectrum Access System
TAC	Technical Advisory Council
WRC	World Radio Conference

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November 16, 2017

The Honorable Darrell Issa
Chairman
Subcommittee on Courts, Intellectual Property and the Internet
Committee on the Judiciary
House of Representatives

The Honorable Suzan K. DelBene
Member
House of Representatives

The number of connected devices—ranging from goods like phones and cameras to connected vehicles to automated manufacturing facilities—is currently estimated in the billions and rising. The Internet of Things (IoT) generally refers to these connected devices (or "things") that use a network to communicate with one another and process data. These connected devices are integrated into the daily activities of consumers, businesses, and government. For example, wearable IoT devices enable users to track information about their health and fitness activities. In agriculture, IoT technology can analyze soil quality and harvest yield to automatically deposit seed in fertile parts of a field. Further, some cities now use connected traffic sensors to monitor traffic flow and air quality. These devices may connect to networks through a wired connection, but the trend in new technology is increasingly to connect wirelessly. Connected wireless devices use radio frequency spectrum (spectrum) to communicate.[1] Wireless communications allow devices to remain connected while mobile but also allow connected devices in locations where a wire may not be possible. While specific estimates vary, wireless IoT devices are expected to grow exponentially and this means many more devices using spectrum. Some experts forecast 25–50 billion devices will be competing for spectrum by 2025. Continued growth in the number of connected devices could require more spectrum be made available or more efficient ways of using available spectrum, more spectrum sharing, or a combination of all three.

[1]Radio frequency spectrum is a finite natural resource of electromagnetic radiation lying between the frequencies of 3 kilohertz and 300 gigahertz. Spectrum is necessary for essential government functions and missions such as national defense, homeland security, weather services, and aviation communication, as well as commercial services such as television broadcasting and mobile voice and data.

The National Telecommunications and Information Administration (NTIA) within the Department of Commerce and the Federal Communications Commission (FCC) are responsible for managing spectrum within the United States. FCC manages spectrum used for consumer, commercial, and state and local public safety purposes, and NTIA oversees spectrum used by the federal government. Both are responsible for planning ways to meet increasing demands for spectrum created by IoT and other wireless devices. You asked us to examine the challenges facing federal spectrum managers and the steps they are taking to address those challenges. In this report we discuss: (1) the spectrum-related challenges selected stakeholders identified due to the anticipated growth of IoT, (2) steps the federal government is taking to plan for the anticipated growth in the demand for spectrum as a result of IoT, and (3) efforts that selected leading countries are undertaking to plan for IoT's spectrum needs and ways that these efforts compare with those of the United States.

To identify the spectrum-related challenges stemming from the expected growth of IoT, we conducted interviews and reviewed relevant hearings, reports and literature.[2] We identified relevant stakeholders (1) by reviewing comments submitted to NTIA in response to its request for comment on the government's role in planning for IoT growth,[3] (2) by reviewing records of three congressional hearings related to IoT growth, and (3) by conducting a review of literature on topics that encompassed academic articles, government reports, and trade journals. We conducted 24 telephone, and in-person interviews with stakeholders, including industrial and commercial users of IoT, nonprofit groups, subject matter experts, manufacturers, and telecommunications companies and FCC and NTIA regarding the spectrum-related challenges presented by the anticipated growth in IoT. The views of these stakeholders are not generalizable to those of all IoT stakeholders in the United States; however, we believe that these interviews provide a balanced and informed perspective on the topics discussed. We then analyzed the results of these interviews and related documents to identify the main themes and develop summary findings. To characterize the views captured during the interviews, we defined the terminology used to quantify the views as follows:

[2]See appendix II for a list of all organizations and individuals interviewed for this report.

[3]NTIA, "Request for Comments on the Benefits, Challenges, and Potential Roles for the Government in Fostering the Advancement of the Internet of Things," January 12, 2017.

- “most” users represents 18 to 24 users,
- “a majority of” users represents 11 to 17 users,
- “several” users represents 6 to 10 users, and
- “some” users represents 3 to 5 users.”

Further, we reviewed the previously mentioned hearings, reports, and journals for additional insight on the spectrum challenges related to IoT and to understand the projected growth of IoT devices. We also reviewed literature concerning the growth of wireless devices, such as smart phones, to determine if there are any lessons learned from the demand these devices placed on spectrum that could be applied to the expected growth of IoT. To identify the steps FCC and NTIA are taking to plan for the anticipated growth in the demand for spectrum as a result of IoT, we interviewed FCC and NTIA officials and reviewed relevant agency documents including reports and plans. We compared FCC’s and NTIA’s efforts against their strategic goals and federal internal control standards for identifying, analyzing, and responding to risks to achieving agency objectives.

To identify the efforts that selected leading countries are undertaking to plan for IoT’s spectrum needs and ways that these efforts compare with those of the United States, we identified leading countries by reviewing trade journals, industry publications, foreign governments’ websites and publications, and asking the stakeholders identified above. Through this process, we identified seven countries of potential interest, all of which have conducted spectrum planning in support of IoT: China, France, Germany, Netherlands, Japan, Singapore, and South Korea. We selected four of these countries—France, Germany, the Netherlands, and South Korea—as having similarities to the United States and being leaders in IoT development, based on additional criteria including the level of their economic development, the maturity of their telecommunications infrastructures, and the comparability of their governments to the United

States and the accessibility of their spectrum planning information.[4] We reviewed documents and conducted telephone and written interviews with officials from the spectrum management agencies in each of these four countries. We also conducted eight telephone and written interviews with officials from telecommunications companies in these four countries, with IoT manufacturers, and with officials from international spectrum planning groups to gather information about IoT development, challenges, and responses to these challenges in the leading countries that we contacted. While the experiences of the interviewees are not generalizable to those of all spectrum-planning officials and IoT stakeholders worldwide, we believe that the information we gathered from them provides a balanced and informed perspective on the topics discussed. See appendix I for completed scope and methodology.

We conducted this performance audit from August 2016 to November 2017 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

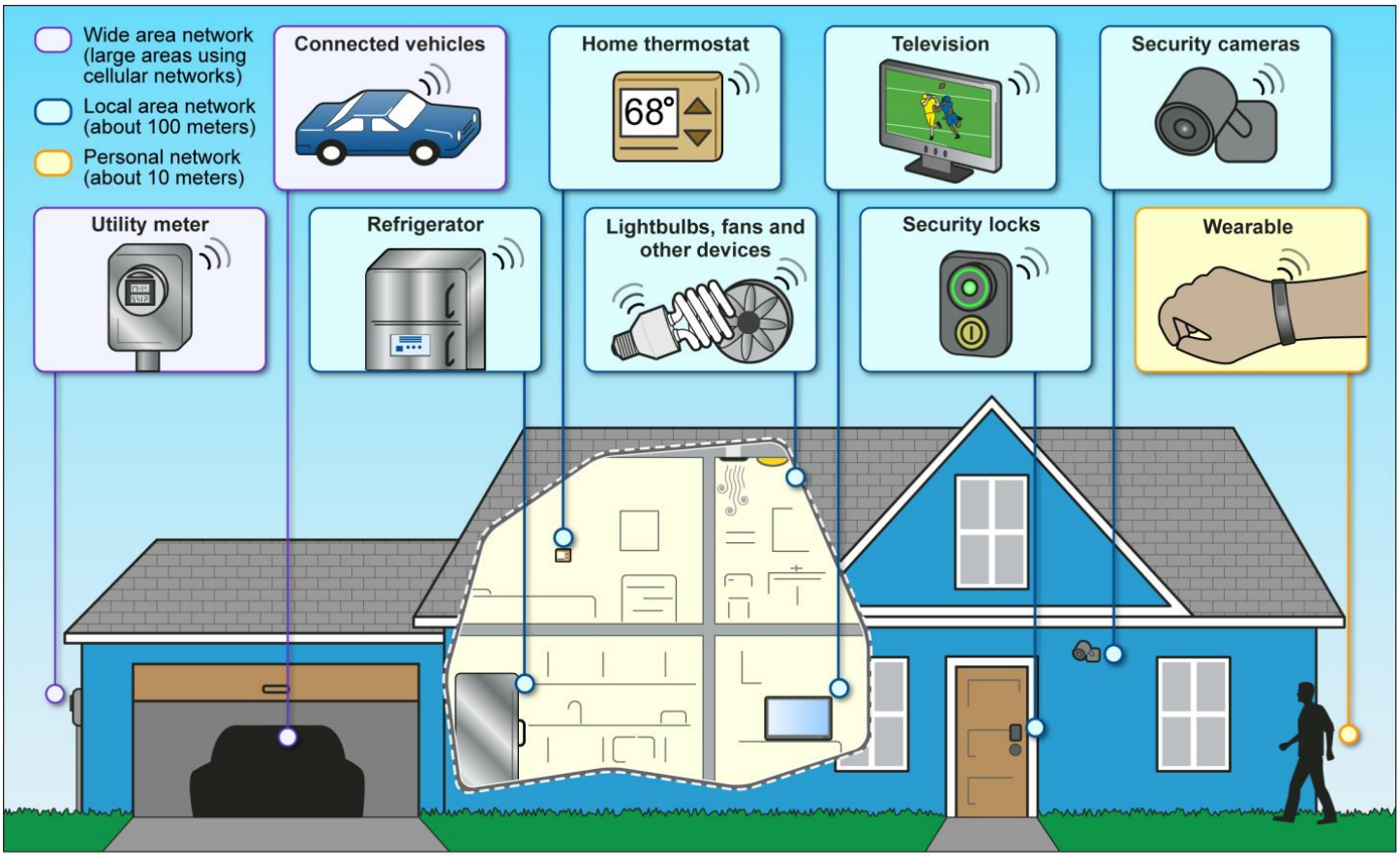
[4]We categorized a country's economy as fully developed if the United Nations Statistics Division categorized it in 2016 as existing in a developed economic region. When determining the maturity of a country's telecommunications infrastructure, we followed the United Nations' International Telecommunication Union (ITU) in categorizing a country's telecom infrastructure as mature if it was included in the top quartile of the 175 countries ranked in ITU's 2016 Information and Communications Technology Development Index. We considered a country to have a government structure comparable to that of the United States if Freedom House's 2016 Freedom in the World report rated it as "free" and the Polity Project categorized it as a "democracy" in 2015. Freedom House's Freedom in the World report and Polity's Polity IV data series are resources for measuring the levels of democracy present in a country. 2015 and 2016 were the most recent versions of these documents available when these decisions were made. While the United Nations Statistics Division classifies South Korea's economy as still developing, the fact that it was first in the ITU's ranking led us to include it in our study. Freedom House, "Anxious Dictators, Wavering Economies: Global Freedom Under Pressure." *Freedom in the World 2016,* accessed January 15, 2017, https://www.freedomhouse.org/report/freedom-world/freedom-world-2016. Center for Systemic Peace, *The Polity Project,* accessed January 15, 2017, http://www.systemicpeace.org/polityproject.html.

Background

Spectrum is a natural resource used to provide a variety of communication services to businesses and consumers, as well as federal, state, and local governments. Businesses and consumers use spectrum for a variety of wireless services including mobile voice and data, WiFi- and Bluetooth-enabled devices, broadcast television, radio, and satellite services. Federal, state, and local governments' uses of spectrum include national defense, law enforcement communication, air-traffic control, weather services, military radar, and first responder communications. IoT applications that rely on spectrum are highly diverse and include connected vehicles, devices in the home, and personal mobile devices.[5] IoT devices communicate using wireless networks, including wide area networks that use cellular networks to cover large areas (e.g., cellular transmission), local area networks that cover about 100 meters (e.g., Wi-Fi within a house), and personal networks covering about 10 meters (e.g., Bluetooth inside a room) (see fig. 1).

[5]Connected vehicles share data wirelessly among vehicles or between vehicles and infrastructure using dedicated short-range communications, a technology similar to Wi-Fi that offers a link through which vehicles and infrastructure can transmit messages over a range of about 300 to 500 meters (about 1,000 to 1,600 feet).GAO, *Intelligent Transportation Systems: Vehicle-to-Vehicle Technologies Expected to Offer Safety Benefits, but a Variety of Deployment Challenges Exist*, GAO-14-13 (Washington, D.C.: November 2013).

Figure 1: Internet of Things Devices and Their Network Characteristics



Source: GAO. | GAO-18-71

Each of these wireless devices, like other wireless IoT devices, communicates using spectrum, and the number of connected devices is expected to increase. In 2013, the number of devices connected to the internet globally was estimated to be over 9 billion.[6] In 2015, the Organisation for Economic Cooperation and Development (OECD) estimated that a family of four had an average of 10 devices connected to the Internet in their household, and that this average will increase to 50

[6]McKinsey Global Institute, *The Internet of Things: Mapping the Value Beyond the Hype* (2015) and Joseph Bradley, Joel Barbier, and Doug Handler, *Embracing the Internet of Everything to capture your share of $14.4 trillion* (Cisco: 2013).

devices by 2022.[7] As companies bring new IoT technologies and services to market and government users develop new mission needs, the demand for spectrum will increase.

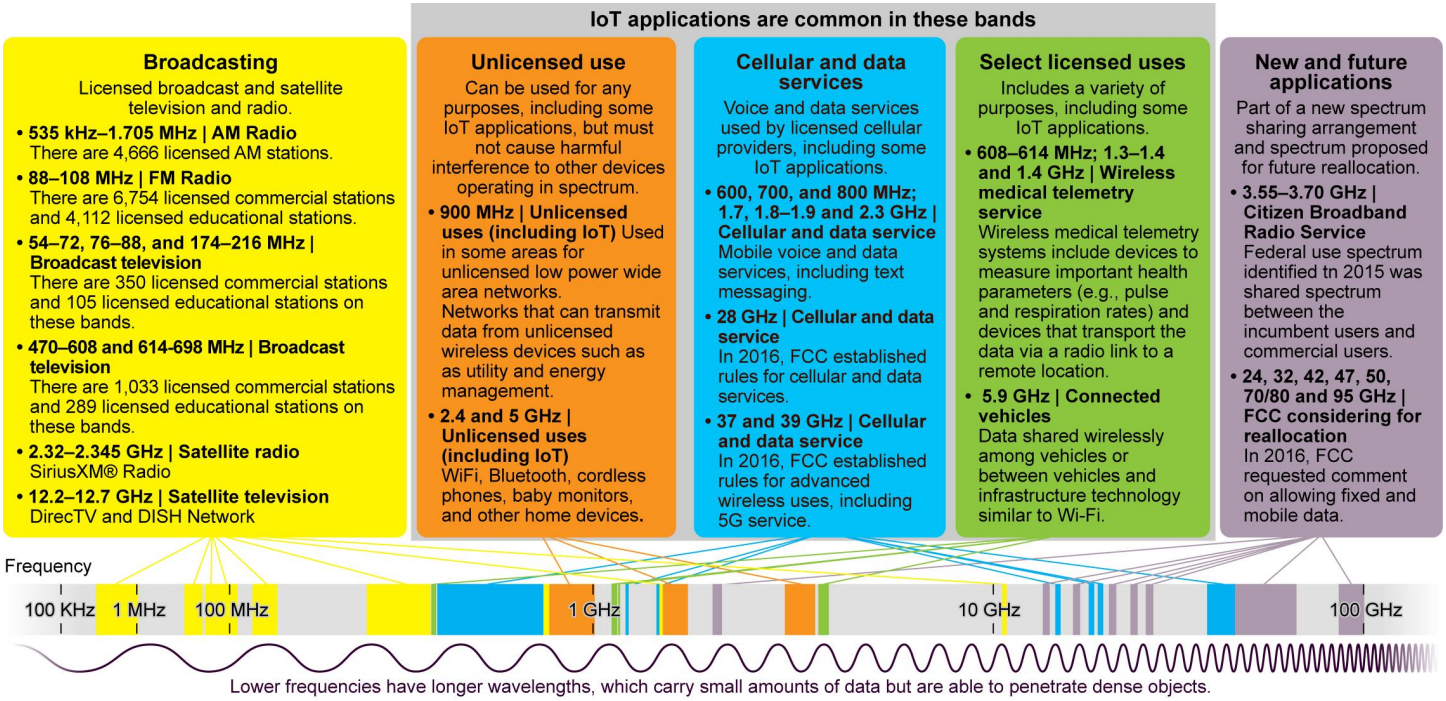
The frequencies, or frequency bands, of spectrum have different characteristics that make them more or less suitable for specific purposes, depending on the specific band (see fig. 2). These bands have different levels of ability to penetrate physical obstacles and cover distances, known as "propagation," and different limits to the amount of information that they can carry, known as data capacity, and are used for different communication purposes. Low frequency bands are characterized by strong propagation, and are used by numerous IoT devices, some of which may only transmit small amounts of information such as temperature, location, or activity status.[8] The strong propagation of low bands means they can transmit over long distances. Mid-band frequencies have higher data capacity than low bands (because, in part, frequency allocations in higher bands are larger, allowing wider channels), as well as, stronger propagation qualities than higher bands. The bands above 30 GHz have high data capacity but relatively poor propagation, to the point that bands at the highest frequencies can be easily obstructed. This spectrum is currently used by a variety of services, including satellite, fixed microwave, and radio astronomy, and is expected to be important for the next generation wireless technology (5G).[9]

[7]This estimate applies to an average family of four located in OECD countries. OECD has 35 member countries that include many of the world's most advanced countries, emerging countries, and countries with emerging economies. OECD, OECD Digital Economy Outlook 2015 (Paris: OECD Publishing, 2015).

[8]Radio frequencies are grouped into bands and are measured in units of Hertz, or cycles per second. The term kilohertz (kHz) refers to thousands of Hertz, megahertz (MHz) refers to millions of Hertz and gigahertz (GHz) to billions of Hertz. The Hertz unit of measurement refers to both the quantity of spectrum (such as 75 MHz of spectrum) and the frequency bands (such as the 5.850 – 5.925 GHz band). Spectrum at lower frequencies is valuable because signals are able to travel greater distances, thus requiring providers to build fewer antenna; high-frequency signals cannot go around obstacles but scatter away, and can be weakened by atmospheric absorption, requiring more antennae.

[9]5G refers to the fifth generation of mobile wireless technology.

Figure 2: Examples of Radio Frequency Spectrum's Commercial Uses



Source: GAO analysis. | GAO-18-71

Notes: The radio frequency spectrum lies between the frequency limits of 3 kHz and 300 GHz. For illustrative purposes, we are only showing a portion of the full radio frequency spectrum.

This graphic is for illustration purposes and is not intended to be a comprehensive list of all allocations and uses.

An interactive graphic on spectrum uses can be viewed at http://www.gao.gov/products/GAO-18-71

FCC is the federal agency responsible for allocating spectrum for various consumer and commercial purposes, assigning spectrum licenses, and making spectrum available for use by unlicensed devices. Licensing assigns frequencies of spectrum, in a specific area, to a specific entity, such as a telecommunications company that operates a network using licensed spectrum. We refer to these bands as licensed spectrum. In some frequency bands, FCC authorizes unlicensed use of spectrum bands—generally referred to as unlicensed spectrum—that is, users do not need to obtain a license to use spectrum. Rather, users of unlicensed devices can share frequencies on a non-interference basis, such as with

home wireless networks, cordless phones, and garage door openers.[10] In addition, FCC supports federal emergency-communications activities.

NTIA is responsible for establishing policy on regulating federal spectrum use, assigning spectrum bands to government agencies, and maintaining spectrum use databases. Additionally, like FCC, NTIA participates in federal emergency communications activities. NTIA also determines what spectrum bands reserved for the federal government can be made available for commercial use.

In managing spectrum, one factor that FCC and NTIA consider is the potential for interference. Harmful interference occurs when two communication signals are either at the same frequencies or close to the same frequencies in the same vicinity, a situation that may lead to degradation of a device's operation or service. Co-channel interference occurs when two communications systems operate on the same frequency assignment in the same vicinity. Adjacent band interference occurs between two communication systems operating on different, but adjacent frequencies in the same geographic area. Another source of interference can be signals on adjacent spectrum bands leaking into another band.

FCC and NTIA work to make more efficient use of spectrum that has been assigned. One means of more efficiently using spectrum is to share it, between and among both federal users and commercial users. In 2017, FCC and NTIA continued oversight of the development of a new-spectrum sharing mechanism called the Spectrum Access System (SAS) in the 3.5 GHz band. Among other things, the SAS allows multiple users access to the same band at different times or places. Within this spectrum band the SAS establishes a three-tiered system of access priority, with federal and non-federal incumbent users having first priority, new non-federal users who have paid for licensed access as second priority, and other users as third priority. This system relies on the SAS to assign frequencies by determining if a frequency is in use by a higher priority user before assigning it to a lower priority user.

[10]A non-interference basis refers to the shared use of a band together with other users, under the conditions that unlicensed devices cannot cause interference to licensed operations nor are they protected from any interference received.

Selected Stakeholders Identified Spectrum Availability and Managing Interference as Challenges Affecting IoT Devices

Stakeholders representing IoT network providers, device manufacturers, users, and federal regulators consistently identified two spectrum-related challenges to the continued growth and development of IoT 1) ensuring the availability of sufficient spectrum and 2) managing the harmful interference from the increasing number of IoT devices.

Spectrum Availability

While not currently a crisis, the stakeholders we spoke to agreed that ensuring the availability of sufficient amounts and the right kinds of spectrum is a key challenge for supporting the growth of IoT. Specifically, stakeholders cited three dimensions of the spectrum availability challenge: the amount, the balance between licensed and unlicensed, and the variety of spectrum bands available. According to some reports, incorrectly anticipating industry needs in any of these areas could weaken IoT growth and development in the United States.

Amount of spectrum: The amount of spectrum needed for IoT devices is expected to increase with their growth. According to a majority of stakeholders we interviewed, FCC will need to continue to make additional spectrum commercially available in order to meet the demand from expected rapid growth in wireless devices, including IoT devices. FCC officials told us the current amount of available spectrum will be sufficient for the growth of IoT unless devices that use a disproportionally large amount of spectrum become more prevalent. Such devices, like those that stream video, could lead to a spectrum shortage that negatively impacts IoT growth. According to several stakeholders spectrum availability will become an issue as use of these devices increases. FCC officials said that cellular providers experienced similar issues when they introduced smart phones, spurring rapid, exponential growth in consumer demand to send and receive wireless data. Despite the potential for a shortage of spectrum for IoT devices, most of the stakeholders agreed that there should not be specific spectrum set aside for IoT devices; rather, some noted spectrum policies should remain flexible, allowing licensees to determine the best use.

Licensed and unlicensed spectrum: A majority of stakeholders said that the spectrum availability challenge includes making both licensed and unlicensed spectrum available. According to FCC staff, FCC is responsible for ensuring sufficient spectrum exists for commercial purposes and will continue to identify new spectrum that can be used for a variety of uses, including by IoT and other wireless devices. This identification of new spectrum includes making spectrum available on both a licensed and unlicensed basis to meet the needs of IoT and other wireless devices. For example, some devices may need to send a signal over a long distance and with a high quality of service to ensure a signal will go through, such as a fire alarm, something licensed spectrum can provide. However, for other devices, cost is a more important consideration. Licensed spectrum has costs that can come from purchasing the license or accessing the spectrum. For example, an official from a supply-chain automation company that develops radio-frequency identification tags told us the lack of inexpensive, low power networks that provide broad coverage is a challenge for their business.[11] With such a network, the company's tags could send out small amounts of data at intervals to help manufacturers track their goods. However, the cost of such a service is important if these tags are to attach to all size packages because paying for GPS or a wireless connections for each would make it unfeasible. According to several stakeholders, the correct balance between licensed and unlicensed spectrum is difficult to know.

Spectrum bands: Several stakeholders indicated that the need to make various spectrum bands available for IoT devices contributes to the spectrum management challenge. As previously described, each band of spectrum has different characteristics, such as the ability to carry data long distances and penetrate obstacles. IoT devices have diverse spectrum needs, such as needing to send a signal over a distance or send a constant stream of information. For example, in the package delivery industry there could be IoT devices, sending signals over a distance, that read the location of the vehicle and direct the driver on a different route based on traffic and deliveries. In addition, there are IoT devices that can monitor containers being delivered including their

[11]Radio-frequency identification, more commonly referred to as RFID, is a form of automatic identification and data capture technology that uses electric or magnetic fields at radio frequencies to transmit information. The RFID system can be used to identify objects, such as manufactured goods, animals, or people that have a RFID tag affixed to it. The tag has a unique identifier and may optionally hold additional information about the object.

location, temperature within the container, and other characteristics. In both these examples, the devices can send signals over long distances to systems that can monitor the information.

Spectrum Interference

Some stakeholders and FCC staff also agreed that managing interference caused by the increasing number of IoT devices will challenge the continued growth of IoT. As previously stated, interference occurs when signals in the same vicinity attempt to access the same spectrum bands or bands close to each other, causing the signals to degrade. This can lead to intermittent access, poor reception, or no reception. As the number of wireless IoT devices grows, the chances of harmful interference increases. The number of IoT devices is predicted to grow so fast the instances of harmful interference could be difficult to track. Furthermore, according to one stakeholder, with devices being made by more manufacturers, not all devices are created of equal quality, potentially further increasing the chance that such devices will cause interference. A recently issued GAO report found that according to FCC staff, the expansion in wireless services and devices, not just IoT, has contributed to interference becoming more of a challenge for FCC.[12] FCC staff agreed that managing interference is becoming more challenging as the number of wireless IoT devices grows. However, according to FCC staff, relatively few complaints pertaining to licensed services involve devices that are compliant with FCC regulations and operating properly.

Managing interference may be particularly difficult in homes where many devices rely on unlicensed spectrum. The FCC Technical Advisory Council's (TAC) report from 2014, expressed concerns that the rapid growth of IoT could exacerbate interference issues in the home.[13] Particularly, the growing reliance on unlicensed spectrum for many consumer IoT devices has contributed to this concern. For example, many IoT devices using unlicensed spectrum, such as digital assistants or wireless speaker systems, use Wi-Fi, Bluetooth or similar technology to transmit a short distance to a smart phone or Wi-Fi router. Not all agree however, that this use is an issue. One spectrum expert we interviewed

[12]GAO-17-75 (May 2017).

[13]In 2014, FCC's TAC IoT working group examined IoT demand, how FCC can foster IoT innovation, and the policy challenges that exist for IoT, among other things. 15th Meeting of the Technical Advisory Council for the FCC (December 4, 2014).

for a recently-issued report said that interference among consumer devices is less likely to be an issue because they only transmit for short durations and over short distances.[14] If the devices only transmit a short distance then many devices can transmit on the same spectrum. Similarly, if devices only transmit for short durations then they can take turns transmitting over the same spectrum.

The Federal Government Has Plans to Meet Spectrum Needs but Does Not Track IoT Devices That Could Cause Congestion

FCC Spectrum Planning

To plan for spectrum needs, FCC has repurposed spectrum by making additional spectrum available for commercial purposes and, according to FCC officials, the agency is continuing to look for additional opportunities to do so. For example, in 2016, FCC issued a final order that opened up high-band spectrum (above 24 GHz) for use with 5G networks and applications. This particular rulemaking from FCC opened up a total of 10.85 GHz of spectrum, 3.85 GHz for licensed mobile use and 7 GHz for unlicensed use.[15] According to FCC, this order follows a technology neutral approach to planning by allowing spectrum users to develop technologies for the spectrum and not have FCC dictate its specific use. Advances in technology that now allow use of spectrum above 24 GHz for high-speed mobile services led the FCC to initiate the proceeding resulting in this order. Previously, this spectrum was best suited for various satellite or fixed microwave applications. As shown in table 1, in recent years FCC has freed up spectrum for licensed use, unlicensed use, and sharing between the two.

[14]GAO-17-75 (May 2017).

[15]*In The Matter of Use of Spectrum Bands Above 24 GHz for Mobile Radio Services,* Report and Order and Further Notice of Proposed Rulemaking, 2016 FCC LEXIS 2470 (2016). In this Report and Order, nearly all the spectrum repurposed was in higher bandwidths that require millimeter wave spectrum. The technology necessary to operate in these higher bandwidths is still being developed.

Table 1: Examples of the Federal Communications Commissions' (FCC) Efforts to Repurpose Spectrum

Year	Description	Total bandwidth repurposed
2016-2017	FCC auctioned spectrum that was previously licensed to television broadcasters, making it available for wireless purposes[a] (70 MHz for licensed use and 14 MHz for unlicensed and wireless microphone use).	84 MHz
2016	FCC reallocated several frequency bands for licensed and unlicensed uses. Bands are shared between new users and incumbent users (3.85 GHz for licensed use and 7 GHz for unlicensed use).	10.85 GHz
2015	FCC auctioned spectrum that is currently occupied by federal and non-federal users for licensed wireless purposes. The spectrum will be shared between current users and new licensees.	65 MHz
2015	An FCC order provided new spectrum for shared wireless broadband use.[b] This order created a framework that authorized spectrum access in three tiers: incumbent access, priority access, and general authorized access.[c]	150 MHz

Source: FCC. | GAO-18-71

[a]The Middle Class Tax Relief and Job Creation Act of 2012 (the 2012 act) required FCC to conduct an auction of broadcast television spectrum to help meet the nation's accelerating spectrum needs. This auction is referred to as an incentive auction because eligible television broadcasters can voluntarily relinquish some or all of their spectrum-usage rights in the auction of the spectrum to mobile providers.

[b]*In the Matter of Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band*, Report and Order and Second Further Notice of Proposed Rulemaking, 30 FCC Rcd 3959 (2015).

[c]The first tier provides access to incumbent users including federal, national defense radar, and commercial satellite. The second tier provides priority access for licensees. The third tier provides access to general authorized access users, which would be authorized to use the spectrum within designated geographic areas but would be required to not cause interference to, and accept interference from incumbent and priority access users. Spectrum use in the band is assigned by Spectrum Access System, which differs from the conventional licensed and unlicensed rules by relying on a framework that adopts the best approach based on local supply and demand.

In 2016, FCC issued a proposed rule to allow mobile uses in an additional 17.7 GHz of spectrum.[16] In 2017, the FCC issued a Notice of Inquiry seeking input on potential opportunities for additional flexibility, particularly for wireless broadband services, in spectrum bands between 3.7 and 24 GHz. However, according to FCC staff, the process of identifying and freeing up new spectrum can take a significant amount of time as FCC must complete a rulemaking and either relocate existing users or define sharing arrangements between the existing users and new users. FCC has also proposed sharing mechanisms it hopes will

[16]2016 FCC LEXIS 2470 (2016).

allow some bands to be used by existing users as well as additional uses in the future. Other efforts to make additional spectrum commercially available have included examining the potential for sharing the 5.9 GHz band that FCC designated for transportation safety.[17] This band was allocated over 15 years ago and designated exclusively for safety communication between vehicles and between vehicles and infrastructure. In recent years, FCC has worked with the automobile industry and Department of Transportation to assess whether all or a portion of that spectrum could be shared. FCC is also monitoring development of specifications to support 5G—the next generation of wireless networks. According to FCC, the 5G technologies that providers develop are projected to bring wireless networks lower latency, better coverage, faster Internet connections, and allow for more connections than the existing cellular network, all of which may enable more IoT devices to be connected.[18] However, 5G technology is still being developed, and while specifications are not fully defined, according to the plans from the standards-making bodies there will be particular standards designed to support IoT communications.

NTIA's Data Gathering and Research

In 2016, NTIA issued a report on the potential roles of the federal government in support of the growth of IoT.[19] It addressed specific questions regarding the spectrum needs and potential interference related to IoT devices and reaffirmed the government's role in supporting technology growth. Furthermore, the report identified ongoing initiatives that support IoT as well as proposed future steps the Department of Commerce can take to further support IoT development. For example,

[17]In 1999, FCC allocated 75 MHz of spectrum—the 5.850 to 5.925 GHz band (5.9 GHz band)—for the primary purpose of improving transportation safety and adopted basic technical rules for operations of dedicated short range communications. In 2003, FCC established licensing and service rules for the 5.9 GHz band to provide a short-range, wireless link for transferring information between vehicles and roadside systems. *In the Matter of Amendment of the Commission's Rules Regarding Dedicated Short-Range Communication Services in the 5.850-5.925 GHz Band*, Report and Order, 19 FCC Rcd 2458 (2004).

[18]Latency is the time it takes for data to travel from one point on the network to another. High latencies may affect the perceived quality of some services such as video or online games.

[19] Department of Commerce, Internet Policy Task Force and Digital Economy Leadership Team, *Fostering the Advancement of the Internet of Things* (January 2017).

NTIA's report proposed that it continue to analyze the usage and growth of IoT devices through its survey used to collect its Digital Nation data.[20] Recent Digital Nation surveys have asked about wearable devices, use of smart televisions, and use of Internet-enabled mobile phones, all uses that include IoT applications.[21] The most recent survey, in 2015, also asked Internet users whether they interact with household equipment or appliances via the Internet.[22] NTIA officials recently told us that they will continue to monitor these connected items to track trends in their use but do not intend to expand the survey to include questions about additional IoT devices. Specifically, in January 2017, NTIA sought out public comment on its November 2017 Digital Nation survey including comment on a proposed questionnaire. NTIA subsequently submitted its proposed questionnaire to Office of Management and Budget for final approval. [23]

NTIA also has ongoing spectrum studies through its Institute for Telecommunications Sciences and the findings may apply to IoT's use of spectrum. As shown in table 2, these studies touch on a number of areas related to IoT including interference issues and spectrum use. NTIA also co-chairs the Wireless Spectrum Research and Development Interagency Working Group that coordinates spectrum-related research and development activities across the federal government, academia, and the private sector.[24] Among other activities, this working group has developed the Wireless Spectrum Research and Development Inventory that, in its 2016 iteration, provides information on completed projects or those

[20]The Digital Nation data survey is conducted every 2 years on broadband adoption in this country and in recent years additional information has been added to the survey. These data are collected as part of the Current Population Survey Computer and Internet Use Supplement, which is sponsored by NTIA and administered by the Census Bureau. In 2015, this survey included interviews of over 52,000 households gathering data on over 120,000 individuals.

[21]The survey asked about the use of smart televisions and Internet enabled phones in its 2011, 2013, and 2015 surveys. It asked about wearable devices for the first time in 2015.

[22]NTIA provides detailed results from IoT-related questions on its website. NTIA, *New Insights from the Emerging Internet of Things*, (June 15, 2016), accessed October 17, 2017, https://www.ntia.doc.gov/blog/2016/new-insights-emerging-internet-things.

[23]For details on the Office of Management and Budget's review see https://www.reginfo.gov/public/do/PRAViewICR?ref_nbr=201708-0660-001, accessed October 17, 2017.

[24]This working group is part of the Networking and Information Technology Research and Development program.

scheduled to be completed between January 1, 2015 and December 31, 2018.

Table 2: Spectrum Studies Currently Being Conducted by National Telecommunications and Information Administration (NTIA)

Current spectrum studies	Goal	Status
Internet of Things (IoT) testbed	To assess the effect of how IoT devices interact on wired and wireless infrastructure as the IoT market grows.	NTIA expects to classify different consumer IoT devices and create models to show the impact on infrastructure when many IoT devices are present.
Spectrum monitoring	Establish an architecture to support a variety of sensing technologies and data to improve usability and analytics.	NTIA is currently working to establish an automated spectrum monitoring prototype.
Electromagnetic compatibility analysis	To characterize the emissions of wireless devices to improve interference detection and avoidance technology.	NTIA is conducting tests of device-to-device interference in wireless environments. Testing will include simulations in a lab and field testing.

Source: NTIA | GAO-18-71

Tracking IoT's Growth

FCC has a strategic goal of promoting economic growth, and one way FCC pursues that goal is by ensuring that there is sufficient spectrum to support commercial demand. Most stakeholders agree that the growth in mobile IoT devices will eventually require additional spectrum to operate effectively. According to some stakeholders we interviewed and reports we reviewed, rapid, unexpected growth in two areas could lead to congestion and interference that could slow the growth of IoT in the United States: (1) high-bandwidth devices[25] and (2) devices that operate in unlicensed bands. Federal standards for internal control instruct agencies to address risks such as these by estimating the significance of the risk, analyzing the likelihood of it occurring, and assessing its nature.[26]

[25]For the purposes of this report, high-bandwidth devices are mobile IoT devices, such as devices designed to stream video, that use more spectrum than an average mobile IoT device.

[26]GAO, *Standards for Internal Control in the Federal Government*, GAO-14-704G (September 2014).

Such assessments can be used to determine how to respond to the potential risks that could prevent agencies from meeting their goals. Rapid growth in high-bandwidth and unlicensed spectrum devices represent risks to FCC achieving its goal of promoting economic growth by ensuring that sufficient spectrum is available.

FCC officials said that the agency tracks industry-produced trends and projections related to spectrum demand and use but does not focus on specific devices. Rather, it relies on network providers to manage and track the spectrum related to specific device types. When more spectrum is needed, FCC officials said that FCC identifies additional spectrum and makes it available to the commercial sector. However, this reactive approach may not adequately address the risks caused by high-bandwidth and unlicensed-spectrum devices.

- High-bandwidth devices: Some stakeholders we interviewed and FCC officials said that rapid increases in high-bandwidth IoT devices could overwhelm current wireless networks. Such IoT devices could include video-streaming devices or unmanned drones, which have much higher data needs and will require a lot of bandwidth. FCC officials said that the supply of spectrum has not always kept pace with demand caused by rapid increases in high-bandwidth devices. For example, the officials said that wireless networks were overwhelmed when providers introduced smart phones. Until then, ringtones represented the bulk of demand for wireless data, but mobile Internet browsing caused the demand for wireless data to increase several fold. In 2014, the FCC TAC warned that new IoT applications could overwhelm networks the same way smartphones and other new technologies have in the past. The TAC recommended that FCC monitor IoT wireless networks with a specific focus on high-bandwidth devices.[27]
- Unlicensed spectrum use: Some stakeholders also said that unlicensed bands are particularly vulnerable to congestion and potential interference because of expected growth in IoT devices. For example, all the commercial, industrial, and personal devices that connect using WiFi and Bluetooth networks use unlicensed spectrum. In 2014, the TAC indicated that the majority of wireless IoT devices will rely on unlicensed spectrum and recommended FCC make sufficient unlicensed spectrum available for devices operating on local

[27] 15th Meeting of the Technical Advisory Council for FCC (December 4, 2014).

and personal area networks, like WiFi and Bluetooth. However, FCC may not have enough information to determine when the amount of unlicensed spectrum is sufficient. While network providers can manage the number of devices on their own licensed networks, this approach does not work for devices that use unlicensed spectrum, and FCC does not track unlicensed spectrum utilization. It does not track use of unlicensed spectrum because congestion of unlicensed spectrum is geographically and technically challenging to track. Specifically, it is geographically challenging because network congestion and demand can vary over very short distances and technically challenging because there are so many bands of spectrum that would have to be tracked at one time and unlicensed spectrum typically propagates over relatively short distances. However, there may be ways to track unlicensed use that does not require monitoring. For example, NTIA's Digital Nation survey provides information on select IoT devices using unlicensed spectrum that could help track unlicensed spectrum use.

While FCC makes additional spectrum available when needed, it lacks an early warning system for high-risk sectors, like high-bandwidth and unlicensed-spectrum devices. The process of identifying and reallocating spectrum is a lengthy process that can take years, including the need to identify new bands, address the needs of existing users on the bands, establish service rules, and license or assign the spectrum for commercial uses. Without tracking the high-bandwidth and unlicensed-spectrum devices, FCC is not assessing a key risk associated with its goal of promoting economic growth. Rapid, unexpected growth in these IoT sectors could lead to spectrum congestion and interference that could slow or halt the economic growth associated with IoT until FCC can make additional spectrum available.

Selected Leading Countries Vary in Spectrum-Planning Approaches for IoT

Approaches to Spectrum Planning in Selected Leading Countries

Like the United States, France, Germany, the Netherlands, and South Korea are among the world leaders in the development of IoT. We contacted public and private officials in these countries to identify their approaches to spectrum planning to address the growth of IoT. Those officials described approaches to planning for future spectrum needs that

are similar to the United States in one area but different in others (see table 3). Specifically, we found that all four countries practice technology neutral spectrum planning, an approach that was broadly supported by the stakeholders we interviewed, including wireless carriers, a technology manufacturer, academics, and a nonprofit group.[28] Some of these stakeholders indicated that this approach to spectrum planning encourages innovation as it allows developers to choose the most appropriate spectrum bands for new technology without having to take the extra step of getting regulators' permission for each new device or application.

Table 3: Spectrum Planning in Selected Leading Countries

Planning activities	United States	France	Germany	South Korea	The Netherlands
Technology-neutral spectrum planning	Yes	Yes	Yes	Yes	Yes
National Internet of Things plan	No	No	Yes	Yes	No
Focus on unlicensed spectrum to support future IoT growth	No	Yes	No	No	Yes
Nationwide low-power wide-area network deployed	No	Yes	No	Yes	Yes

Source: Federal Communications Commission and spectrum management agencies from select leading countries. | GAO-18-71

Two of the selected leading countries, Germany and South Korea, have developed national IoT plans focused on developing IoT for industry; however, only South Korea has a plan that specifically addresses spectrum issues. South Korea's national IoT plan seeks to increase collaboration among IoT stakeholders, promote innovation, and develop services for the global market in order to promote productivity and efficiency in Korean business. South Korea also developed a mid- to long-term spectrum plan to respond to the expected growth in demand for spectrum as IoT expands and 5G cellular networks are deployed. Released in 2016, the plan intends to makes more spectrum available to support new services such as smart homes, smart factories, smart cities,

[28]Technology neutral planning allows spectrum users to develop technologies for the spectrum and not have FCC dictate its specific use.

remote medical treatment, and unmanned vehicles. Specifically, the South Korean spectrum plan that includes IoT and establishes the following goals:

- almost doubling the amount of available spectrum available, expanding from 44 GHz of available spectrum to 84 GHz by 2026, and
- increasing the efficiency of spectrum use, promoting spectrum sharing, and advancing international coordination in spectrum planning.

Officials from France and the Netherlands told us that making more unlicensed spectrum available is a high priority in their spectrum planning. These officials told us that unlicensed spectrum promotes greater innovation by lowering barriers to access, and many IoT devices are expected to be designed to operate on unlicensed bands. German and Dutch officials told us that numerous smart city IoT applications have been developed in their respective countries, most of which operate on unlicensed spectrum. For example, German and Dutch networks use unlicensed spectrum for purposes that include managing street lighting, preventing the theft of property such as bicycles, monitoring parking spaces, and managing agricultural resources.

To provide service options for low power IoT devices, private companies in France, the Netherlands, and South Korea developed nationwide low-power wide-area networks (LPWAN) which use unlicensed spectrum to transmit data.[29] These LPWANs use the 800 and 900 MHz bands to transmit data from wireless IoT devices such as sensors and location trackers. Signals in these bands can be transmitted over long distances and can penetrate obstacles. According to one LPWAN provider, the distance served by a LPWAN site is greater than a single cellular network site. However, according to the same LPWAN operator, the bands used for LPWAN networks have limited data capacity compared to those used by cellular networks. According to officials and telecommunications industry stakeholders in these countries, LPWANs offer several potential benefits including low barriers to entry, low costs, and broad coverage.

[29]There are multiple technologies that can be used to operate LPWANs, including LoRa, Random Phase Multiple Access, and Sigfox. In the United States, LPWANs have been developed using each of these technologies.

According to a Dutch telecommunications industry stakeholder most devices that use LPWANs transmit only small amounts of data. A telecommunications industry stakeholder in France told us that the long range and strong propagation of these LPWANs make them useful for utility metering data and South Korean official told us that LPWANs are used to transmit location or temperature data. For example, in the Netherlands, LPWANs are used to monitor water depth and quality, manage street lighting, and to track the location of business inventory and personal property. In France, LPWANs are used for similar tracking as well as smoke detectors. Other uses for the LPWANs are currently in development. For example, a representative of a Dutch telecommunications company told us that in the Netherlands, IoT devices operating on the nationwide LPWAN are being tested at an airport for use in logistical processes such as baggage handling. Additionally, a Dutch railway station is experimenting with IoT technology that monitors rail switches using the LPWAN, and depth sounders at the port of Rotterdam have been fitted with devices to connect them to the network. South Korean officials said that the LPWAN in their country also provides specialized location-tracking services.

In the United States, companies have built LPWANs to support a variety of uses including location tracking, temperature monitoring, and water metering. However, one supply chain automation company told us that while it would not benefit any individual company enough to make it efficient to construct a large scale LPWAN in the United States, such a network would prevent many small losses and inefficiencies, a development that would add up to make a significant impact on the economy. According to FCC officials, the LPWAN market is still developing in the United States. The development of a nationwide LPWAN in the United States may face some of the same challenges that confronted the development of other nationwide communications networks. For example, providing service in rural areas and local issues presented challenges to planning the public-safety broadband network and building nationwide cellular network s.[30] In addition, a major mobile service provider now offers subscription-based LPWAN service available

[30]The Middle Class Tax Relief and Job Creation Act of 2012 created the First Responder Network Authority within NTIA and required it to establish a nationwide, interoperable public-safety broadband network (Pub. L. No. 112-96, 126 Stat. 156 (2012) (codified at 47 U.S.C. §§ 1401-1457). The network is intended to be a high-speed, wireless data and voice telecommunications network for first responders.

in the United States using some of its licensed spectrum from its cellular network

Selected Leading Countries Face International Coordination and Potential Spectrum Congestion Challenges

Selected leading countries take many similar approaches to each other and the United States to managing spectrum in order to address related challenges (see table 4). Like the United States, spectrum-planning officials in France, Germany, and the Netherlands told us that it was necessary to coordinate spectrum planning with other countries on their borders. Officials in each of these countries told us that European spectrum planning is complicated by the number of countries that share borders. Germany, for example, borders nine other countries. As each country is responsible for its own spectrum planning, if their plans are not closely coordinated, there is a potential for cross-border interference. This coordination is complicated by the fact that European countries have legacy spectrum allocations, and these must be accommodated in spectrum planning. The United States, by contrast, shares its border with only Mexico and Canada. According to FCC officials, both of these countries generally align their spectrum plans to those of the United States, reducing interference issues.

Table 4: Spectrum Management Approaches in Selected Leading Countries

Monitoring activities	United States	France	Germany	South Korea	The Netherlands
Represented in regional spectrum-planning association	Yes	Yes	Yes	Yes	Yes
Concerned that spectrum congestion may be an issue in the future	Yes	Yes	Yes	No	No
Priority on increasing spectrum sharing	Yes	Yes	Yes	Yes	Yes
Government directly tracks spectrum congestion	No	Yes	Yes	No	No

Source: Federal Communications Commission and spectrum management agencies from select leading countries. | GAO-18-71

In order to facilitate international coordination of spectrum planning, each of the four selected leading countries, like the United States, belongs to a regional spectrum-planning association that works to harmonize spectrum planning among member states.[31] Officials of regional groups we spoke with told us that harmonizing can reduce interference issues across borders and facilitate interoperability of devices across different countries. Officials from the manufacturing and telecommunications industries told us that this interoperability creates a larger potential market for IoT devices, thereby improving the economies of scale for the manufacture of IoT devices and reducing production costs. Regional planning associations are also taking steps to prepare their member countries for the spectrum needs of IoT. For example, an official of one association, the Inter-American Telecommunication Commission, told us that in 2016 it held a workshop on "machine-to-machine" technologies that brought together spectrum planners and stakeholders from IoT-related industries.[32] Regional-planning associations also represent their member countries at World Radiocommunications Conferences (WRC).[33] An official from one association told us that due to the diverse nature of IoT devices and applications it is unnecessary for IoT to be explicitly addressed as an agenda item at WRCs. However, the official further stated that the spectrum needs of specific IoT applications— including low power sensors, robotics, and connected vehicles—are included on the agenda. For example, the next WRC is scheduled for 2019 and includes an agenda item addressing connected vehicles, which are closely linked to IoT.

Spectrum-planning officials in each of the selected leading countries told us they are concerned about the potential for spectrum congestion, due to growth in the number of IoT devices. However, like FCC in the United States, these officials do not currently believe such congestion presents an immediate problem. Representatives of the four countries we spoke with told us that one way that they address the potential challenge of spectrum congestion is through the use of spectrum-sharing

[31]See appendix III for a list of regional planning associations and their members.

[32]The term "machine-to-machine technologies" refers to technology that enables machines to communicate with one another and drive action.

[33]WRCs are held every 3 to 4 years by the United Nations' International Telecommunication Union in order to revise the Radio Regulations, the international treaty governing the use of the radio-frequency spectrum and the orbits of satellites.

arrangements. Representatives from Germany specifically stressed the importance of finding additional sharing arrangements in response to the expected spectrum needs for IoT. In 2016, both France and the Netherlands initiated pilot programs for spectrum sharing in which multiple users' access the same bands while prioritizing use by the licensee. These pilot programs are similar to the dynamic-sharing model that FCC adopted in 2015, as described previously. However, whereas the model adopted by FCC has three tiers of users, the model used by France and the Netherlands has only two, and lacks the third tier of general access users.

Unlike the United States, officials from Germany and France told us that they directly monitor spectrum congestion. For example, German officials told us that there are spectrum-monitoring services at six locations around the country, and that they perform mobile measurements of spectrum congestion. FCC officials told us that their primary means of tracking congestion is to communicate with spectrum licensees. According to officials from the Netherlands, the Dutch spectrum management agency takes a similar approach and has struck an agreement with a group of telecommunications companies to share information concerning IoT's interference and congestion issues. Officials also told us that it is easier to monitor spectrum congestion in smaller countries, as there is simply less geographical space to monitor. Nevertheless, officials in France, Germany, and the Netherlands told us that monitoring spectrum is a challenging task, as it is difficult to determine how many wireless devices are active at any given time.

Conclusions

FCC has a strategic goal to promote economic growth and effective spectrum management represents a key way that FCC can support meeting that goal. To that end, FCC officials said that the agency continuously seeks to make additional spectrum available and broadly tracks spectrum demand. However, stakeholders and FCC's own technical advisors have identified rapid, unexpected growth in both high-bandwidth devices and unlicensed spectrum as risks to effective spectrum management. By overwhelming existing networks before FCC can make more spectrum available, rapid growth in spectrum demand could slow or halt IoT's potential to facilitate economic growth. Absent additional efforts to assess the risks to effective spectrum management by focusing on high-bandwidth and unlicensed-spectrum devices, spectrum congestion and interference could slow IoT growth.

Recommendations

We are making the following two recommendations to the Chairman of FCC.

The Chairman of FCC should track the growth in high bandwidth IoT devices, such as video-streaming devices and optical sensors. (Recommendation 1)

The Chairman of FCC should track the growth in IoT devices relying on unlicensed spectrum. (Recommendation 2)

Agency Comments and Our Evaluation

We provided a draft of this report to FCC and the Department of Commerce for their review and comment. FCC provided comments in a letter, which is reprinted in appendix IV. FCC and the Department of Commerce provided technical comments that we incorporated as appropriate.

In its written comments, FCC did not concur with our recommendation that it track growth in high-bandwidth devices. FCC noted that it continues to believe that the best approach to track growth of devices is by monitoring overall traffic statistics and forecasts and how these devices affect aggregate spectrum requirements for all applications and services. However, FCC noted that it would task the Technological Advisory Council (TAC) to periodically review the state of the IoT ecosystem to ensure that the planned communications infrastructure is sufficient to support the needs of the growing sector and advise on any actions the FCC should take. We continue to believe that tracking the growth of high-bandwidth devices is necessary to avoid the potential spectrum shortage and that the TAC may be able to help FCC accomplish that.

FCC did not concur with our recommendation to track IoT devices that rely on unlicensed spectrum. FCC noted that it may not be practical to determine which devices qualify as IoT or quantify their effect on spectrum utilization. As a result, FCC said that the best way to monitor growth in unlicensed IoT devices is to continue to monitor published papers and conferences and work with industry. However, since most of the projected IoT growth is expected to occur in unlicensed bands that are not protected from interference, we continue to believe that FCC

should place a greater focus on tracking IoT devices in these bands. For example, the TAC may also be well positioned to help FCC track unlicensed IoT devices.

As agreed with your offices, unless you publicly announce the contents of this report earlier, we plan no further distribution until 30 days from the report date. At that time, we will send copies to the Secretaries of Homeland Security and Commerce, the Chairman of FCC, and appropriate congressional committees. In addition, the report will be available at no charge on the GAO website at http://www.gao.gov.

If you or members of your staff have any questions about this report, please contact me at (202) 512-2834 or goldsteinm@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. Major contributors to this report are listed in appendix IV.

Mark L. Goldstein
Director, Physical Infrastructure Issues

Appendix I: Objectives, Scope, and Methodology

We were asked to examine the challenges facing federal spectrum managers and the steps they are taking to address those challenges. In this report we discuss: (1) the spectrum-related challenges stakeholders identified due to the anticipated growth of IoT, (2) steps FCC and NTIA are taking to plan for the anticipated growth in the demand for spectrum as a result of IoT, and (3) efforts that selected leading countries are undertaking to plan for IoT's spectrum needs and ways that these efforts compare with those of the United States.

To identify the spectrum-related challenges stemming from the expected growth of IoT, we reviewed documents from the Federal Communications Commission (FCC) and the National Telecommunications and Information Administration (NTIA), the two federal agencies that have direct authority over spectrum planning. Further, in order to identify relevant literature for review, we (1) conducted a key word search of data bases; (2) searched IoT and spectrum related websites, such as those of cellular carriers, telecommunications industry groups, and nonprofit organizations; (3) reviewed prior GAO reports on IoT and spectrum issues; and (4) asked FCC and NTIA officials, researchers, and non-profit organizations to identify relevant documents. Through our literature search, we identified a number of documents, including academic reports, government reports, congressional committee hearings, and trade journals addressing the projected growth of IoT to understand the number of devices that would be relying on the spectrum in the coming years. We also reviewed literature concerning the growth of other wireless devices, such as smart phones, and the burden they place on the spectrum, to assess if there are any lessons learned from the demand these devices placed on the spectrum that could be applied to the expected growth of IoT.

In addition, we interviewed FCC and NTIA officials, and conducted 24 telephone and in-person interviews with officials from industry associations, industrial and commercial users of IoT, nonprofit groups, subject matter experts, manufacturers, and telecommunications companies to obtain their perspectives on the challenges presented by the expected growth of IoT. The experiences of the stakeholders are not generalizable to those of all IoT stakeholders in the United States; however, we believe that the information we gathered from selected

stakeholders provides a balanced and informed perspective on the topics discussed. We identified relevant stakeholders by reviewing comments submitted to NTIA in response to its request for comment on the government's role in planning for IoT growth,[1] reviewing congressional hearings, and conducting a literature review encompassing academic articles, government reports, and trade journals. We interviewed officials from businesses that manufacture Internet-connected devices or equipment that would be considered part of IoT, including agriculture, telecommunications, and manufacturing. We spoke with these officials to gather information about the spectrum challenges they face as businesses working with and developing IoT devices. We then analyzed the results of these interviews and related documents to identify the main themes and develop summary findings. To characterize the views captured during the interviews, we defined the terms to quantify the views as follows:

- "most" users represents 18 to 24 users,
- "a majority of" users represents 11 to 17 users,
- "several" users represents 6 to 10 users, and
- "some" users represents 3 to 5 users."

To identify the steps FCC and NTIA are taking to plan for the anticipated growth in the demand for spectrum as a result of IoT, we interviewed FCC and NTIA officials and reviewed agency reports and documents. We interviewed officials to understand any agency plans to address spectrum needs for IoT devices and how these plans aligned with the spectrum planning for other wireless devices. We reviewed agency reports and documents on spectrum planning, IoT planning, and the role of the federal government in planning for IoT. Specifically, we reviewed comments submitted in response to NTIA's request for comment and the final report developed in response to the comments received on the role of the federal government. To identify other relevant reports and literature from FCC and NTIA, we asked officials at the meetings and conducted a literature search. We also compared those planning efforts against FCC's and NTIA's strategic goals and the federal internal control standards related to risk management. Specifically, we compared FCC's planning against its strategic goal to promote economic growth and national leadership in telecommunications, and NTIA's efforts against its mission to expand the use of spectrum by all users and to ensure that the Internet

[1]NTIA (Apr. 6, 2016).

remains an engine for continued innovation and economic growth. We also assessed the efforts of both agencies against leading practices that we previously developed for identifying, analyzing, and responding to risks related to achieving agency objectives.

To identify the efforts that selected foreign governments are taking to plan for the expected spectrum needs of IoT and ways their efforts compare with those of the United States, we surveyed trade journals, industry publications, and foreign governments' websites and publications. Through this survey, we identified seven countries of potential interest, all of which have conducted spectrum planning in support of IoT: China, France, Germany, Netherlands, Japan, Singapore, and South Korea. We selected four of these countries—France, Germany, the Netherlands, and South Korea—as being like the United States and leaders in IoT development based on additional criteria including the level of their economic development, the maturity of their telecommunications infrastructures, the comparability of their governments to the United States, and the accessibility of their spectrum-planning information. We categorized a country's economy as fully developed if the United Nations Statistics Division categorized it in 2016 as existing in a developed economic region. When determining the maturity of a country's telecommunications infrastructure, we followed the United Nation's International Telecommunication Union (ITU) in categorizing a country's telecom infrastructure as mature if it was included in the top quartile of the 175 countries ranked in ITU's 2016 Information and Communications Technology Development Index.[2] We considered a country to have a government structure comparable to that of the United States if Freedom House's 2016 Freedom in the World report rated it as "free" and the Polity Project categorized it as a "democracy" in 2015.[3] Finally, we considered the extent to which information could be efficiently procured from each country under consideration. We reviewed documents and conducted telephone and written interviews with officials from the spectrum management agencies in each of these four countries. We also

[2]While the United Nations Statistics Division classifies South Korea's economy as still developing, the fact that it was first in the ITU's ranking led us to include it in our study.

[3]Freedom House, "Anxious Dictators, Wavering Economies: Global Freedom Under Pressure." *Freedom in the World 2016,* accessed January 15, 2017, https://www.freedomhouse.org/report/freedom-world/freedom-world-2016. Center for Systemic Peace, *The Polity Project,* accessed January 15, 2017, http://www.systemicpeace.org/polityproject.html. 2015 and 2016 were the most recent versions of these documents available when these decisions were made.

conducted eight telephone and written interviews with officials from foreign telecommunications companies, IoT manufactures, and international spectrum-planning groups to gather information about IoT development, challenges, and responses to these challenges in the leading countries that we contacted.

We conducted this performance audit from August 2016 to November 2017 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Appendix II: Agencies, Organizations, and Individuals GAO Interviewed

Table 5: Agencies, Organizations, and Individuals GAO Interviewed Regarding the Spectrum Needs of the Internet of Things (IoT) in the United States

Categories of entities interviewed	Interviewees
Federal agencies	Federal Communications Commission
	National Telecommunications and Information Administration
	Congressional Research Service
Industrial and commercial users of IoT	Barcoding
	Case IH
	Deere & Co.
	O-I
Industry associations	Consumer Technology Association
	CTIA
	National Association of Manufacturers
	Telecommunications Industry Association
	U.S. Chamber of Commerce
	Wi-Fi Alliance
	World Shipping Council
Manufacturers of IoT technology	Qualcomm
	Samsung
Non-profit groups	New America Foundation
	Public Knowledge
	Technology and Innovation Foundation
Subject matter experts	Jeffrey Reed, Ph.D. (Virginia Polytechnic Institute and State University)
	Douglas Sicker, Ph.D. (Carnegie Mellon University)
Telecommunications companies	AT&T
	Sigfox
	Verizon

Source: GAO. | GAO-18-71

Table 6: Foreign and International Agencies and Organizations GAO Interviewed Regarding the Spectrum Needs of the Internet of Things (IoT)

Categories of entities interviewed	Interviewees
Spectrum-planning agencies	Agence Nationale des Fréquences (France)
	Agentschap Telecom (Netherlands)
	Bundesnetzagentur (Germany)
	Ministry of Science, ICT, and Future Planning (South Korea)
International spectrum-planning associations	European Conference of Postal and Telecommunications Administrations
	Inter-American Telecommunication Commission
	International Telecommunication Union
Manufacturers of IoT technology	Adeunis FR
	Hager
Telecommunications companies	KPN
	Suez
	Sigfox[a]

Source: GAO. | GAO-18-71

[a]We spoke with Sigfox regarding its networks in the United States and Europe.

Appendix III: Regional Spectrum-Management Associations and Their Member States

Table 7: Regional Spectrum Management Associations and Their Member States

Regional spectrum-management associations	Member states		
Asia-Pacific Telecommunity	Afghanistan	South Korea	Samoa
	Australia	Laos	Singapore
	Bangladesh	Malaysia	Solomon Islands
	Bhutan	Maldives	Sri Lanka
	Brunei Darussalam	Marshall Islands	Thailand
	Cambodia	Micronesia	Tonga
	China	Mongolia	Tuvalu
	North Korea	Myanmar	Vanuatu
	Fiji	Nauru	Viet Nam
	India	Nepal	
	Indonesia	New Zealand	
	Iran	Pakistan	
	Japan	Palau	
	Kiribati	Papua New Guinea	
		Philippines	

Regional spectrum-management associations	Member states		
African Telecommunications Union	Algeria	Ethiopia	Republic of the Congo
	Angola	Gabon	Sao Tome and Principe
	Benin	Gambia	Senegal
	Burkina Faso	Ghana	Sierra Leone
	Burundi	Guinea	Somalia
	Cameroon	Guinea-Bissau	South Africa
	Central African Republic	Kenya	Sudan
	Chad	Lesotho	Swaziland
	Comoros	Liberia	Tanzania
	Cote d'Ivoire	Libya	Tunisia
	Democratic Republic of the Congo	Madagascar	Uganda
		Malawi	Zambia
	Djibouti	Mali	Zimbabwe
	Egypt	Mauritania	
	Equatorial Guinea	Mauritius	
		Mozambique	
		Niger	
		Nigeria	
Arab Spectrum Management Group	Algeria	Kuwait	Saudi Arabia
	Bahrain	Lebanon	Somalia
	Comoros Islands	Libya	Syria
	Djibouti	Mauritania	Sudan
	Egypt	Morocco	Tunisia
	Iraq	Oman	United Arab Emirates
	Jordan	Palestine	Yemen
		Qatar	

Regional spectrum-management associations	Member states		
European Conference of Postal and Telecommunications Administrations	Albania	Greece	Poland
	Andorra	Hungary	Portugal
	Austria	Iceland	Romania
	Azerbaijan	Ireland	Russian Federation
	Belarus	Italy	San Marino
	Belgium	Latvia	Serbia
	Bosnia and Herzegovina	Liechtenstein	Slovak Republic
	Bulgaria,	Lithuania	Slovenia
	Croatia	Luxembourg	Spain
	Cyprus	The former Yugoslav Republic of Macedonia	Sweden
	Czech Republic		Switzerland
	Denmark	Malta	Turkey
	Estonia	Moldova	Ukraine
	Finland	Monaco	United Kingdom
	France	Montenegro	Vatican City
	Georgia	Netherlands	
	Germany	Norway	
Inter-American Telecommunication Commission	Antigua and Barbuda	Ecuador	Saint Lucia
	Argentina	El Salvador	Saint Vincent and the Grenadines
	Barbados	Grenada	Suriname
	Belize	Guatemala	The Bahamas
	Bolivia	Guyana	Trinidad and Tobago
	Brazil	Haiti	United States of America
	Canada	Honduras	Uruguay
	Chile	Jamaica	Venezuela
	Colombia	Mexico	
	Costa Rica	Nicaragua	
	Cuba 1	Panama	
	Dominica	Paraguay	
	Dominican Republic	Peru	
		Saint Kitts and Nevis	
Regional Commonwealth in the Field of Communications	Azerbaijan Republic	Kazakhstan	Tajikistan
	Armenia	Kyrgyz Republic	Turkmenistan
	Belarus	Moldova	Uzbekistan
		Russian Federation	Ukraine

Source: GAO. | GAO-18-71

Appendix IV: Comments from the Federal Communications Commission

Federal Communications Commission
Washington, D.C. 20554

November 1st, 2017

Mark L. Goldstein
Director, Physical Infrastructure Issues
U.S. Government Accountability Office
Washington, D.C. 20548

Dear Mark:

We commend the GAO for the quality and thoroughness of the draft report on IoT. To ensure sufficient spectrum is available for IoT, the report recommends the FCC should track the growth in (1) high-bandwidth IoT devices and (2) IoT devices that rely on unlicensed spectrum.

IoT encompasses a broad array of innovative devices and services operating on spectrum the Commission has provided for licensed services and unlicensed devices. IoT operations conducted over licensed spectrum are generally interspersed with other types of uses such as voice, video and Internet traffic. Accordingly, the Commission's strategy has been to provide flexibility in the use of existing spectrum bands and continue to add to the supply of both licensed and unlicensed spectrum. For example, in the past few years we conducted successful AWS-3 and TV Incentive auctions, established a Citizen's Broadband Radio Service, and provided access to nearly 11 GHz of spectrum in our Spectrum Frontiers proceeding. Any of the spectrum bands made available through these actions could be used for IoT.

Rather than attempting to distinguish particular high-bandwidth IoT applications, we believe the best approach is to monitor growth of overall traffic statistics and forecasts by organizations such as Cisco and how they affect aggregate spectrum requirements for all applications and services. For example, there is likely little value in distinguishing a streaming IoT video camera from an over-the-top video program service as their impact on spectrum will be approximately the same. We will, however, continue to work closely with industry to monitor developments such as reflected by the Commission's Technological Advisory Council (TAC) report and recommendations on IoT produced at the end of 2015. In addition, we will task the TAC to periodically review the state of the IoT ecosystem to ensure that the planned communications infrastructure is sufficient to support the needs of this growing sector and to advise on any actions that the Commission should take.

We appreciate the desire to track IoT devices that rely on unlicensed spectrum. At a high level, we maintain a database of all unlicensed devices that are certified to comply with the Commission's technical rules. However, it would not be practical to determine which of these devices qualify as IoT. For example, any Wi-Fi router could be used to connect with devices such as a wireless baby video monitor, or it might not be used for such a purpose. Moreover, the Commission has no data as to whether

certified device was sold in high volumes or never sold at all. In addition, it is difficult to quantify a direct relationship between unlicensed IoT devices and the impact on spectrum because they generally use protocols that are designed for sharing in a crowded spectrum environment and the context in which they are used greatly affects their network impact. We believe the best way to monitor growth in unlicensed IoT devices is to continue to monitor relevant information such as from published papers and conferences and work with industry.

Using these methods, we will continue to track the growth and evolution of IoT and work to ensure that its spectrum needs together with those of the many services supported by the nation's wireless infrastructure will continue to be met.

Sincerely,

Julius Knapp, Chief
Office of Engineering and Technology
FCC

Donald Stockdale, Chief for
Wireless Telecommunications Bureau
FCC

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Appendix V: GAO Contact and Staff Acknowledgment

GAO Contact

Mark Goldstein, (202) 512-2834 or goldsteinm@gao.gov

Staff Acknowledgments

In addition to the individual named above, Keith Cunningham (Assistant Director); Eric Hudson (Analyst-in-Charge); Camilo Flores; Adam Gomez; Josh Ormond; Andrew Stavisky; Hai Tran; and Michelle Weathers made key contributions to this report.

Appendix VI: Accessible Data

Agency Comment Letter

Text of Appendix IV: Comments from the Federal Communications Commission

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November 1st, 2017

Mark L. Goldstein

Director, Physical Infrastructure Issues

U.S. Government Accountability Office Washington, D.C. 20548

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Office of Engineering and Technology FCC

Donald Stockdale,

Wireless Telecommunications Bureau FCC

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